TENSILE STRENGTH CAPACITY OF GROUT-FILLED TUBULAR STEEL

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By

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(BARTLEMY LIM)

ABSTRACT

The tensile strength capacity of grout-filled steel will be investigated to see whether there is any significant contribution from the grout to increase the resistivity against failure when in extreme tension. Although the tensile capacity of a grout is very low compared to steel, a noticeable change in the grout-filled steel should be acquired since there is tensile strength in grout. This can be done by comparing the effect of high tension force in grout-filled tubular steel and hollow tubular steel. Any difference in the ultimate yield strength will indicate the influence of the presence of grout filled in the steel. It is expected that the tension required for the grout-filled steel and the hollow steel to fail is significantly different, which will be higher for the grout-filled steel compared to the hollow steel.

ACKNOWLEDGEMENT

First of all, thanks to God the Almighty for the opportunity and blessing that He bestowed upon me. Then, a special thanks to my dedicated and caring supervisor, Assoc. Prof. Dr. Narayanan Sambu Potty for his guidance, time, and knowledge in supervising my final year project. This project was a success due to his perseverance to solve problems occurs during the planning and designing stage. Not to be forgotten all the lab technicians and lab assistants who help me a lot during the fabrication and experimental stages of my project. Also, I would like to extend my gratitude to all my friends who involve directly or indirectly in my project. Lastly, I would like to take this opportunity to thank my family members who gave me support and encouragement in my studies.

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INTRODUCTION

1.1 Background of Study

The use of steel as construction material has seen a phenomenal growth in the last few years. It has been used in the commercial and industrial sector for a long time. It is the best material for constructing support structures due to their efficiency in providing lateral stiffness, hence limiting inter-storey as well as overall lateral deformations. Steel is a man-made metal containing 95% or more iron. The remaining constituents are small amounts of elements derived from raw materials and also elements added to improve certain properties. Carbon partake a percentage of 1-2% and a smaller amounts of manganese, nickel etc. Carbon improves the strength of steel but reduces ductility. Structural steel is steel available in various shapes and forms utilised to support loads and resist the various forces to which a structure is subjected.

1.2 Problem Statement

As the structure ages, the strength of the steel also reduces or compromise naturally or accidentally. Among the causes for damaging a steel structure is corrosion, dent, force overload, etc. Repair or replacement of the weak part is essential if the structure is still needed to be used. Solution to strengthen the weak part must be efficient as well as cost effective. The conventional method is to replace the weak or damage member with a new member through cut and weld procedure. This is a complicated and tedious method since a lot of procedure is required. First of all, a temporary structure is required to support the damage structure. Then, careful grinding or cutting of the damaged part is carried out. A precisely measured new part then is fitted in and welded. Any miscalculation could cause major problem.

But, one of the best solutions for this matter is to strengthen the steel structure by grouting. The grout which is a cementitious material will fill in any empty space or gap in the hollow steel. Once the grout is hardened, it will form a solid structure together with the steel. Even though this method is a common practice in the industry, there is no thorough investigation on the effect of grout in tensile strengthening of tubular steel. One of the reasons is difficult to conduct a tensile strength test on tubular steel because of the difficulty in gripping sample. Thus, special samples need to be fabricated for testing purpose.

1.3 Significance of Research

Various studies on the compressive strength of concrete-filled steel had been done. Significant results in increment of ductility and energy absorption capacity had been proven. The usage of concrete-filled steel also has been applied widely in all industries. This application had helped a lot to the industries that deal with large load or force. If there are any additional of permanent loads to be applied at a newly design structure, the design of the steel do not have to be increased to accommodate the extra load. Instead, concrete-filled steel can be used for the structure. For any existing structure that require to be strengthen due to additional load will be applied, the support steel can be simply grouted or filled with concrete to increase the compressive strength capacity. It is an efficient and effective method of strengthening steel structure without having to replace or add any new member. Some steel member in the structure might be in compression while others will be in tension. For steel member in compression, grouting or concrete filling is proven to increase the compressive strength capacity of the steel. But, for member under tension, there is still no record on the increment of the tensile strength if grouting on the steel structure is carried out. This is because concrete is a material used to withstand any high compression load, but not tension stress. Thus, any significant increase of tensile strength of concrete-filled steel compare to hollow steel can validate or certify grouting as a procedure that can improve the strength of steel structure under compression or tension stress.

1.4 Objective

The objective of this research is first of all to determine the best design for tensile strength test on tubular steel. Once the design is obtained and proved to be able to be tested for tensile strength, the effect of grout in a steel structure under tension stress is determined. Any contribution of grout in increasing the ultimate yield strength of the steel will be observed.

1.5 Scope of Study

Test for tensile or pull-out force will be carried on grout-filled circular steel tube and also hollow circular steel tube. Both of the circular steel for the test must be of the same grade, size, and shape. This to show any difference in the tensile strength between the two steel tubes is due to the present of the grout.

Besides that, two different diameter sizes will be used to observe the effect of diameter on strength increment. The outer diameters used are 48.3mm and 60.3mm with thickness of 3.2mm for both samples. Different diameter will affect the size area of the grout which effects the contribution of tensile strength.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

2.1.1 Steel

Steel is one of the most used materials in building a structure support. Supports using steel can provide high resistant in lateral seismic in a steel framed structure. It will efficiently provide lateral stiffness, hence limiting inter-storey as well as overall lateral deformation. For that reason, the cyclic performances of axially loaded tubular members are used as bracing elements.

Among the parameters that are important in seismic design are:

- *Tensile capacity*
- Initial and post buckling compressive resistance
- Ductility capacity
- Energy dissipation
- Mid-length lateral deformation of bracing members

Buckling and yielding are usually allowed in the diagonal members, which preventing any inelastic response at other members. This is important for a practical seismic design for ultimate conditions (Goggins et al, 2006)

2.1.2 Concrete

Another material widely used in construction is concrete. Concrete is the mixture of cement, water and aggregates. Mixture of cement and water will produce a paste that coats the surface of fine and coarse aggregates. Through a chemical process called hydration, the cement paste will harden and gains strength to form the rock-like mass known as concrete. To produce the desired design strength and properties of the concrete, the proportioning and mixing of the ingredients should be calculated and determined. A properly designed concrete mixture will possess the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 to 15 percent cement, 60 to 75 percent aggregate and 15 to 20 percent water. Entrained air in many concrete mixes may also take up another 5 to 8 percent (Portland Cement Association, 2009). The compressive strength of concrete is very high. Ordinary Portland Cement has an average of compressive strength 20-50 Mpa, for a standard mixing of concrete. It is an ideal material for slab with the capability to withstand high compression load. Unlike the compressive strength, tensile strength of a concrete is very low and seldom concrete is used to withstand any tension force. The brittle characteristic of a concrete contribute the concrete to crack easily under a pull-out force. Concrete cracking is described by one damage variable; debonding and sliding are modeled by an inelastic strain and another damage variable measuring the amount of nonrecoverable energy (Boudan-Cussac, et el, 1999). According to American Concrete Institute (ACI), the splitting tensile strength of concrete can be predicted by the 0.5 power relation from its compressive strength (ACI 318) while many researchers have investigate the accurate relation between the tensile strength and compressive strength of a concrete to be 0.69 power relation. Tensile strength predictions from these relations were compared with test results assembled from various sources (Oluokun, 1991).

2.1.3 Combination Usage of Concrete and Steel

With the high compressive strength of concrete and the high tensile strength of steel, the combination of both materials can produce an ideal matter that is high in both tensile and compressive strength. Both compressive and tensile strength will be improved as any compression load will be absorbed by concrete material while any tension force will be resisted by steel. Thus, steel bar reinforce concrete is produced. It is a significant combination that being used widely in all construction industries worldwide. Another application of concrete and steel material is concrete-filled steel or grout-filled steel. Hollow steel will be filled with concrete or grout at the center. Grout is defined by ACI as “a mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents.” Grout may also contain fly ash, slag and liquid admixtures (National Ready Mixed Concrete Association, 1993, 2005.)

2.1.3.1 Concrete/Grout-Filled Steel

In a concrete-filled tube (CFT) column, the steel tube encloses the concrete core and is used as both longitudinal and lateral reinforcement. Thus, the steel section is subjected to biaxial stresses consisting of longitudinal compression and hoop tension, which interact and affect the mechanical behavior of the column. Whether the load was applied to the entire section or only to the concrete section of the CFT, the stability of the column was lost by a combination of local buckling and crushing (Johansson and Gylltoft, 2002). Using non-linear finite element analysis of CFT, good confining effect can be provided by the tubes to concrete especially when the diameter-thickness ratio is small for CFT of circular section. Local buckling of steel tube is not likely to occur. For a square section, the tubes do not provide too much confining effect to concrete especially when the diameter-thickness ratio is large, thus local buckling of steel tube is very likely to take place. The confining effect of CFT for square section with steel reinforcing tie section is enhanced by the reinforcing tie when the tie spacing is small and the tie number (or tie diameter) is large. Local buckling of steel tube is prevented by the reinforcing tie and is not likely to occur. Both the lateral confining pressure and the material degradation parameter decrease with the increasing of diameter-to-tube thickness ratio. When the diameter-to-tube thickness ratio is small, due to the lateral confinement from the steel tube, the lateral confining pressure and the material degradation parameter tend to be large. When the diameter-to-tube thickness ratio is large, due to the lack of lateral support from the steel tube, the lateral confining pressure and the material degradation parameter tend to be small (Hu et al., 2003). CFT is a material with excellent performance resulting from the confined effect of steel with concrete and high design versatility. However, designing a CFT and processing the beam to column connection with CFT is difficult. Thus, an intermediate part has been design by using steel tube member with a diaphragm (NS column) to enables simplified design (Shimura, Okada, Yamaguchi, 1998). Analytical studies on the long term behavior of a circular concrete-filled steel tubular (CFT) column under central axial loading are formulated based on compatibility, equilibrium conditions and a number of assumptions for the way of the load are applied. Kwon et al, 2005 considered two loading cases, which are:

i. Load applied only at the inner core concrete of a CFT column
ii. Load applied simultaneously on both of the inner concrete and the steel tube

Experiments were conducted to determine the formulation of the CFT columns and the results were agreeable with the theoretical analysis, thus proven the validity of the assumptions used in the formulation analysis and also the accuracy of the analysis method. For the (i) loading case, the strain of both the concrete and the steel tube are distributed non-linearly along the longitudinal axis of the CFT column because of the bond stress and the confinement effect. Slip may occur and increases with time since there is a difference of strain distribution among the concrete and the steel tube, which also increases with time. For (ii) loading case of uniform distribution of strain on the concrete as well as the steel tube along the longitudinal axis of the column, as loading time increases, the stress acting on the concrete section decreases while the stress of the steel tube section increases. The confinement effect of concrete does not appear at initial loading or in long term deformation (Kwon et al, 2005).

2.1.4 Further Research

The compression analysis of concrete-filled steel has been done by few researches. It is crucial information as the application of concrete-filled steel are being widely used by all the industries. It is also one of the best solutions to reinforce any damage or corrode steel. The steel structures do not require any new additional or replacement member, but only being filled with concrete or grout. But, in some part of the structure, member might be under tension stress such as brace member in a frame structure. Thus, reinforcing the member with concrete or grout require verification if improvement in tensile strength can be obtained. Any significant contribution of concrete towards the tensile strength of steel is needed.

Besides that, details research on the tensile strength of grout-filled steel also should be conducted. The situation and condition of the steel should be varied to imitate any possible damage that could occur on a steel structure. Among recommended testing to be conducted are bent steel, corroded steel, and stressed out steel.

CHAPTER 3

METHODOLOGY

3.1 Practical Testing

To determine the tensile strength capacity of the steel, tubular steel will be used in this experiment. The tubular steel will be exerted with high tension force which is more than the yield strength capacity of the steel. To observe the effect of grout on the tensile strength capacity of the tubular steel, the test will be conducted on hollow tubular steel and on grout-filled tubular steel. The tension force required to yield both the steel sample will be recorded and analyzed. All tension force at failure indicates the maximum stress force that can be resisted by the steel. Comparison of both data will show the contribution of grout in the tensile strength.

3.1.1 Sample Fabrication

First of all, the design of the tubular steel sample is determined. Theoretical calculation of the steel strength is calculated. Every connection of the steel is ensured not to fail during the pullout test but only the area of grout-filled is fail. Few designs of steel samples were inspected. The best design is the one that can transfer the maximum tensile force to the tubular steel. The tubular steel sample also should only fail due to the high tension that exceeding the yield stress of the steel. Any other failure such as joint failure should be avoided so that the actual tension stress required to yield the steel can be observed. For this experiment, six (6) samples will be fabricated with three samples using 48.3mm outer diameter tubular steel and another three samples using 60.3mm outer diameter. Out of the three samples, two samples will be filled with grout while one sample is hollow tubular as a control sample.

3.1.2 Sample Testing

Once samples are done fabricated and the grout reached the optimum hardening period, which is 28 days, tensile strength then will be conducted on the samples. Universal Testing Machine is used to conduct the test with the capacity of the machine to exert force up to 1000 kN.

3.2 Theoretical Testing

3.2.1 Research/Calculation

Comparison on any available record related to grout-filled steel will be studied to determine if there is any available proof or data regarding the increase of tensile strength when it is filled with concrete or grout. Any application of this concept also will be observed and reviewed if any failure or problem occurs. Then, the type of problem or failure will be inspected to determine the relationship between the failure and the concrete-filled.

3.2.2 Computer Software Simulation

Besides that, modeling simulation can be carried out to obtain a theoretical possible effect of the grout-filled to the whole structure. Measurement of forces and load will be computed and analyzed by suitable software such as Structural Analysis Computer System (SACS).

3.3 Materials:

- Circular hollow steel tube
- Grout
- Steel plate

3.4 Equipments:

- Universal Testing Machine
- Grouting equipment
- Welding equipment

CHAPTER 4

RESULT AND DISCUSSION

4.1 Sample Design

To conduct the tensile test on the circular steel tube, first of all, the circular steel tube must be designed and fabricated. Since it is a hollow tube, clamping it to the pull-out machine will crush the steel tube at the contacted area between the clamp of the machine and the end of the steel tube. Thus, failure can occur at the crushed end of the steel. Any weak point will affect the performance of the steel thus reducing its tensile strength capacity.

Hence, theoretical analysis is carried out on all the possible design of the circular steel tube. The main criterion of the design is to transfer maximum tension stress on the grout-filled area of the steel until failure occurs, and the failure must be due to the applied tension force only.

For the final design of the circular steel tube, steel plates will be attached at both end of the steel. The plates and the steel tube are welded together with a certain length, type and thick of welding as designed.

The purpose of the steel plates is to provide grip area for the tension machine. Thus, the clamp of the machine can grip firmly unto the plates while pulling the whole steel structure.

4.2 Tension Capacity Analysis

Because the plates and steel tube are welded together, calculation is required to determine the minimum welding needed at the connecting area between the plates and steel tube. The thickness of the steel plate also should be calculated theoretically to ensure that it can withstand the load imposed.

Details of the steel tube, steel plates and welding required:

Tube A (diameter of 48.3mm)

	No.1		No.2	
	Outer diameter (mm)	Inner diameter (mm)	Outer diameter (mm)	Inner diameter (mm)
	48.35	42.43	48.41	42.38
	48.3	42.29	48.43	41.98
	48.14	42	48.59	42.39
Average	48.26	42.24	48.48	42.25
Thickness (mm)	3.01		3.12	
Surface area (mm^2)	428.15		443.69	
Max yield strength (kN/mm^2)	0.43		0.43	
Ultimate load (kN)	428.15 x 0.43 = 184.10		443.69 x 0.43 = 190.79	

Steel plate	
Ultimate Load = Maximum Yield Strength x Thickness x Width	
Thickness	1 cm
Maximum yield strength	43 kN/cm^2
Ultimate load to withstand	500 kN

Thus, minimum width of steel plate required = $\frac{\text{Ultimate Load}}{\text{Max Yield Strength x Thickness}}$	$\frac{500}{43 \times 1}$ = 11.63 cm

Welding	
Weld strength = $0.7dL\rho_{yw}$	
stress strength to withstand	500 kN
d = weld thickness	5mm
ρ_{yw} = weld strength capacity	200 N/mm^2
L = weld length Since at each end of tubular steel will have 4 section of connection between the steel plate and the tubular steel, thus, there are 4 L.	$L = \frac{\text{Weld Strength}}{4 \times 0.7 \times d \times \rho}$ $= \frac{500000}{4 \times 0.7 \times 5 \times 200}$ = 178.57 mm

Table 4.2.1: Tube A details

Tube B (diameter of 60.3mm)

	No.1		No.2	
	Outer diameter (mm)	Inner diameter (mm)	Outer diameter (mm)	Inner diameter (mm)
	60.51	53.16	59.93	54.44
	60.58	52.23	60	54.03
	60.3	52.88	60.13	54.36
Average	60.46	52.76	60.02	54.28
Thickness (mm)	3.85		2.87	
Surface area (mm^2)	685.30		515.57	

Max yield strength (kN/mm^2)	0.43	0.43
Ultimate load (kN)	685.30 x 0.43 = 294.68	515.57 x 0.43 = 221.70

Steel plate	
Ultimate Load = Maximum Yield Strength x Thickness x Width	
Thickness	1 cm
Maximum yield strength	43 kN/cm^2
Ultimate load to withstand	500 kN
Thus, minimum width of steel plate required = $\frac{\text{Ultimate Load}}{\text{Max Yield Strength x Thickness}}$	$\frac{500}{43 \times 1}$ = 11.63 cm

Welding	
Weld strength = $0.7dL\rho_{yw}$	
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Table 4.2.2: Tube B details

Thus, in comparison of the steel plates, welding connection and the tubular steel, the ultimate load of the tubular steel is the lowest. Hence, the tubular steel will yield first whenever there is high tension force..

Refer to Appendix A for details of the sample.

4.3 Failure of Steel Tube

Sample of the steel tube is tested under tensile strength. Load is imposed until the sample is failed or breaks. The pattern of the failure is similar to the failure of a steel bar, which will go through ultimate strength, yield strength, necking then rupture. This shows that the sample can be used to test the tensile strength of tubular steel. Photo of the ruptured tubular steel can be referred in the Appendix B.

4.4 Experimental Analysis of Strength Increment

Through pull-out test carried on the samples, there is an obvious increment of tensile strength capacity when grout is used to fill in the tubular steel. The results of both hollowed and grout-filled tubular steel are as follow:

Tube A (diameter of 48.3mm)

Tube details	Yield strength (kN)	Ultimate strength (kN)	Rupture (kN)
Hollowed (control)	148.31	150.601	129.448

Tube details	Yield strength (kN)	Ultimate strength (kN)	Rupture (kN)
Grout-filled (1)	144.344	153.445	142.262
Increment	-3.966	2.844	12.814
Grout-filled (2)	138.00	152.77	145.98
Increment	-10.31	2.169	16.532

Table 4.4.1: Tensile strength capacity of Tube A

<u>Ultimate Strength Analysis</u>

In comparison of the tensile strength capacity of hollowed and grout-filled tubular steel, an increment of at least 2 kN in the grout-filled tubular steel. In percentage:

Tube 1: (2.844 / 150.601) x 100% = 1.89%

Tube 2: (2.169 / 150.601) x 100% = 1.44%

Average of strength increase = (1.89 + 1.44) / 2

= 1.66%

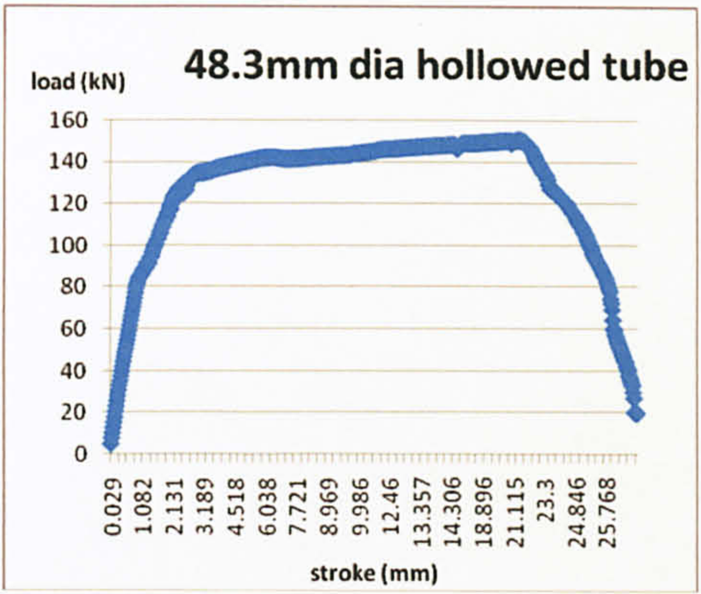

Figure 4.4.1: 48.3 mm diameter hollowed tubular steel.

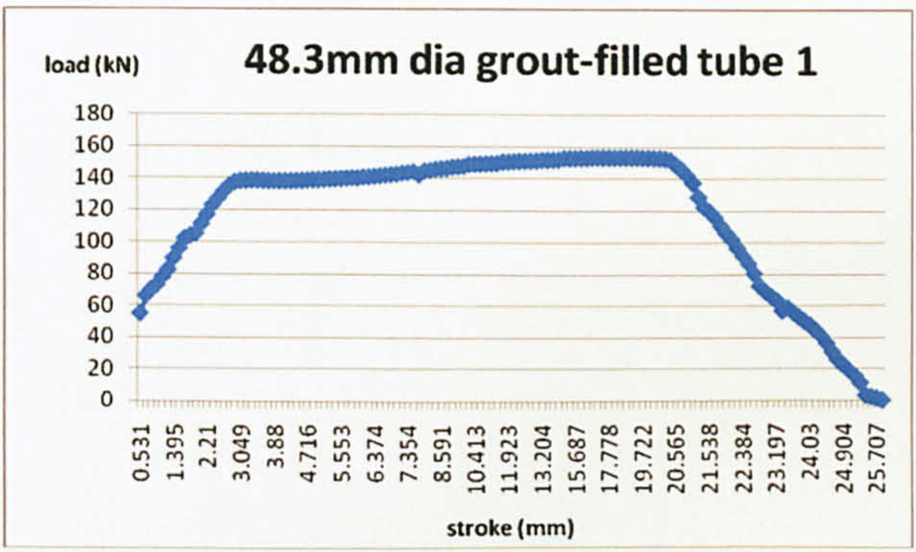

Figure 4.4.2: 48.3 mm diameter grout-filled tubular steel (1).

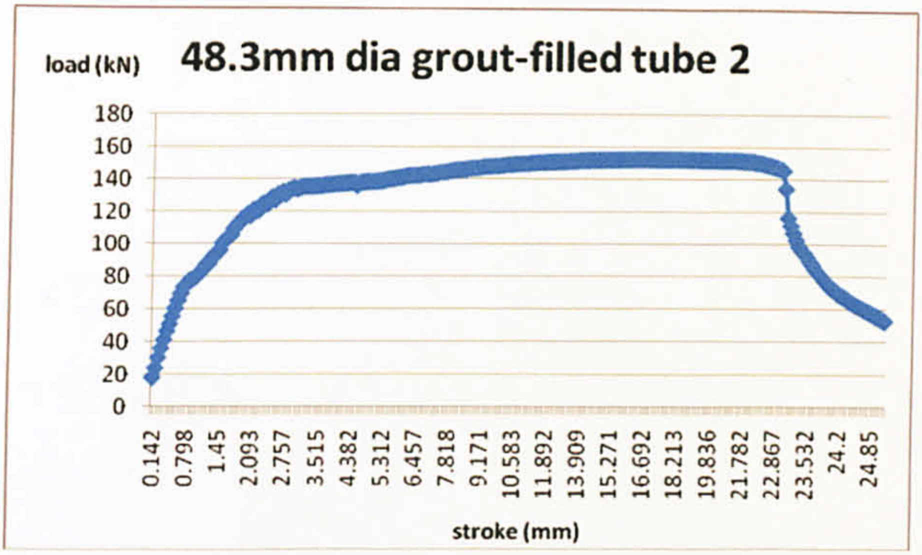

Figure 4.4.3: 48.3 mm diameter grout-filled tubular steel (2).

Tube B (diameter of 60.3mm)

Tube details	Yield strength	Ultimate strength	Rupture
Hollowed (control)	117.842	139.855	98.978

Tube details	Yield strength	Ultimate strength	Rupture
Grout-filled (1)	149.22	149.255	99.32
Increment	31.378	9.4	0.342
Grout-filled (2)	132.116	149.704	123.227
Increment	14.274	9.849	24.249
Grout-filled (3)	147.116	170.253	163.718
increment	29.274	30.397	64.74

Table 4.4.2: Tensile strength capacity for Tube B

Ultimate Strength Analysis

In comparison of the tensile strength capacity of hollowed and grout-filled tubular steel, an increment of at least 9 kN in the grout-filled tubular steel. For Tube 3, the increment is more than 30 kN. In percentage:

Tube 1: (9.4 / 139.855) x 100% = 6.72%

Tube 2: (9.849 / 139.855) x 100% = 7.04%

Tube 3: (30.397 / 139.855) x 100% = 21.73%

Average of percentage strength increase = (6.72 + 7.04 + 21.73) / 3

= 11.83%

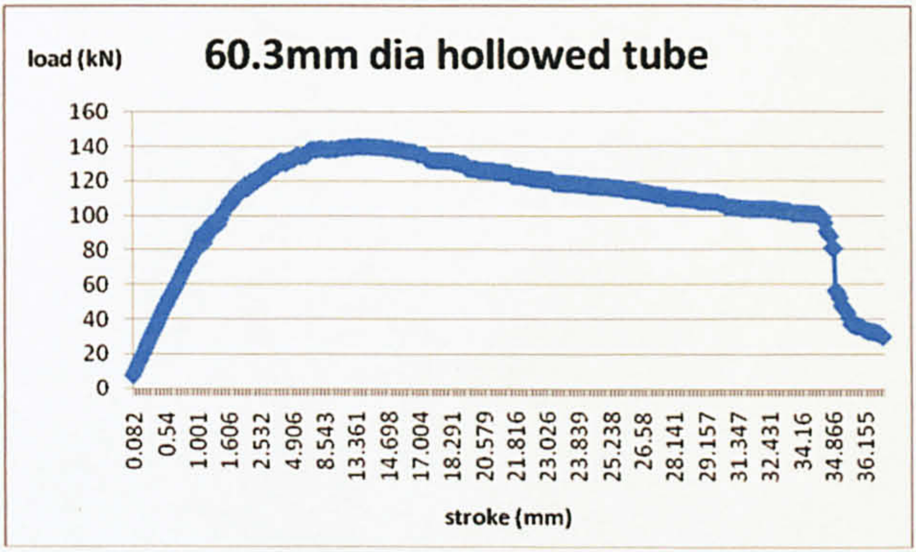

Figure 4.4.4: 60.3 mm diameter hollowed tubular steel.

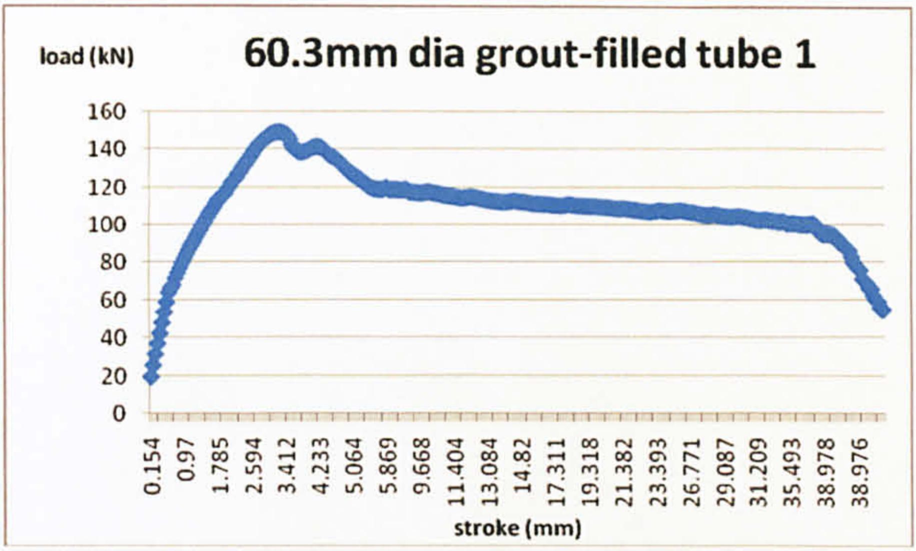

Figure 4.4.5: 60.3 mm diameter grout-filled tubular steel (1).

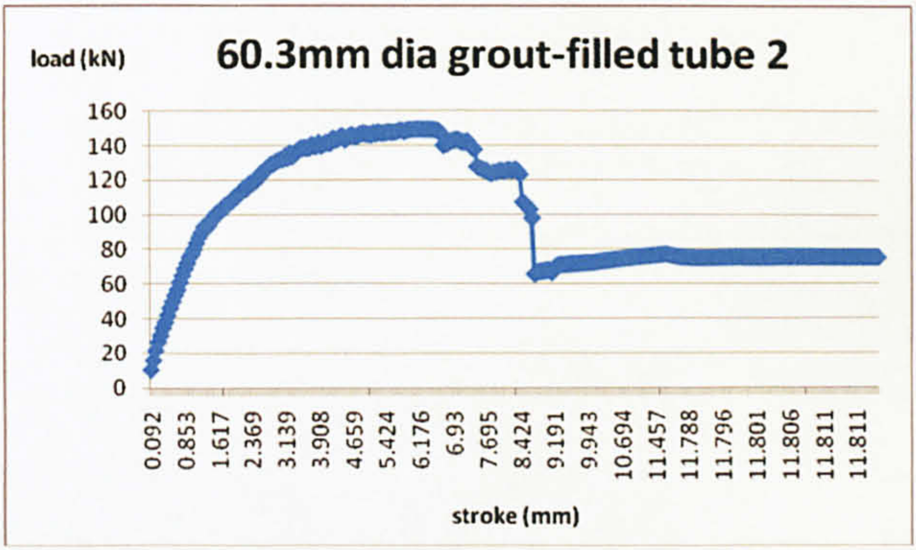

Figure 4.4.6: 60.3 mm diameter grout-filled tubular steel (2).

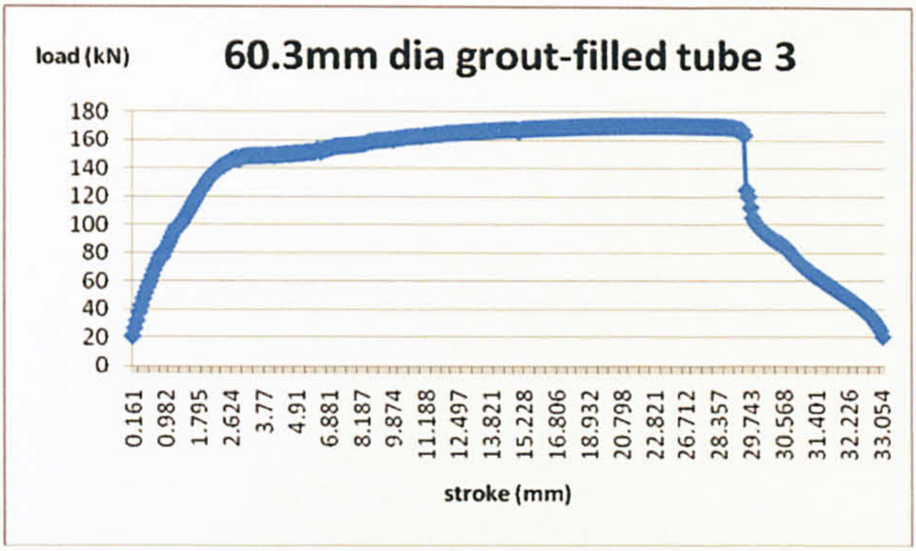

Figure 4.4.7: 60.3 mm diameter grout-filled tubular steel (3).

For more accurate result of the pull-out test, please refer to APPENDIX C.

Discussion

For tube A, the increment is small but still might be helpful in strengthening a damage structure. Since steel structure can be in tension and tensile depending on the situation, it will be useful knowing that grouting can be used on steel structure, regardless the of the condition of the steel, either it is tension or tensile.

For tube B, the percentage increment is even larger. This is due to the larger cross sectional area of the grout in the tubular steel. Tube 1 & 2 have an increment of 7%, while Tube 3 has an increment of 21%. This is due to the inner surface of the tubular steel. For Tube 3, corrosion is observed at the surface of the steel, thus giving it firmer grips, which lead to the higher tensile strength increment. Thus, it shows that the increment is high when used in the right situation or condition of the tubular steel.

Besides that, the fabrication also plays an important role to ensure that the sample will be tested correctly and efficiently. If the steel plate is not welded in the same alignment for both end of the tubular steel, the pull-out machine will twist the tubular steel when clamping the steel plate. This could cause the tubular steel to be under torsional load. This could add load on the tubular steel and causing it to fail at a lower tensile force.

4.5 Increment of Strength in Relation to the Sectional Area of Grout

Tube A

Sectional area of grout = π (42.25 mm)^2 / 4

= 1401.98 mm^2

Tube B

Sectional area of grout = π (53.52 mm)^2 / 4

= 2249.69 mm^2

Through this experiment, it is ensured that the increment in tensile strength capacity is due to the present of grout filling only. Other factors such as type of grout, curing of grout, and type of steel used, are controlled and ensured consistent for the entire sample. Thus, the difference of increment obtained can be assumed due to the sectional area of the grout. The larger the sectional area of grout, the higher increment of tensile strength capacity will be obtained.

4.6 Failure Analysis

Once the sample failed or ruptures in the pull-out test, the failure of the sample is analyzed and observed to determine the cause of type of failure occurs.

From observation, the grout inside the tubular steel where the failure occur, the grout is still bonded with the inside surface of the tubular steel. But, due to the tensile force applied to the sample, the grout is flaky and elongated. It can be seen that the grout failed in layers. The grout is not crushed or slipped from the tubular steel. Thus, it can be seen that the tensile force applied to the sample have been distributed to the grout as well.

4.7 Hazard Analysis

While conducting this research, HSE should always be practiced and applied. A lot of hazard or accident could occur if work is not done properly.

4.7.1 Experiment

- When steel is required to be cut, heavy machine is used such as grinder, milling machine, and hand saw. Wear PPE all the time such as safety goggle, glove and apron. Understand and follow every safety procedure for the machine used. Any malfunction or incident must be reported to the lab technician in charge.
- When tensile test is carried out, tensile load machine will be used. Understand and follow all the safety precaution necessary. Wear PPE all the time. Ensure that while conducting experiment, no personal should be near to machine as breaking of the steel could cause flying of sharp pieces.

4.7.2 Research

- Hazard regarding ergonomic could occur while conducting research on reading materials. Ensure the comfort while doing work by applying the correct position of working.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

From this experiment, it shows that the testing of tubular steel is possible by adding 2 steel plates at the end of the tube. Then, the pull-out machine will clamp unto the steel plate to exert tensile force. The tensile force will be distributed evenly unto the test sample.

When the tubular steel is exerted with high tensile strength, the steel will fail in the same manner as a steel rode will fail. It will go through few faces, such as ultimate strength, yield strength, rupture, necking region and strain hardening region. Before rupture occur to the tubular steel, it will go through necking stage, where the tubular steel will be elongated and reducing the diameter of the cross-sectional area until that section fail and rupture.

The grout-filled tubular steels show a relatively higher tensile strength capacity compared to the hollowed tubular steel. The addition of grout has contributed to the tensile strength capacity. Besides that, the cross-sectional area of the grout also influences the percentage increment of the capacity. The higher the sectional area of the grout, the higher percentage of increment in the tensile strength capacity of the tubular steel will be obtained.

As a recommendation, there is a lot of variation can be done to improve and investigate the tensile strength capacity of grout-filled steel. Different sizes of steel can be tested to determine the relationship between the size of cross-sectional are of grout and the percentage increment of tensile strength. Besides that, different shape of steel also can be used to verify the best shape that gives the highest tensile strength capacity. Furthermore, the surface condition of the steel also can be varied to establish any significant improvement toward the tensile strength capacity of the grout-filled steel.

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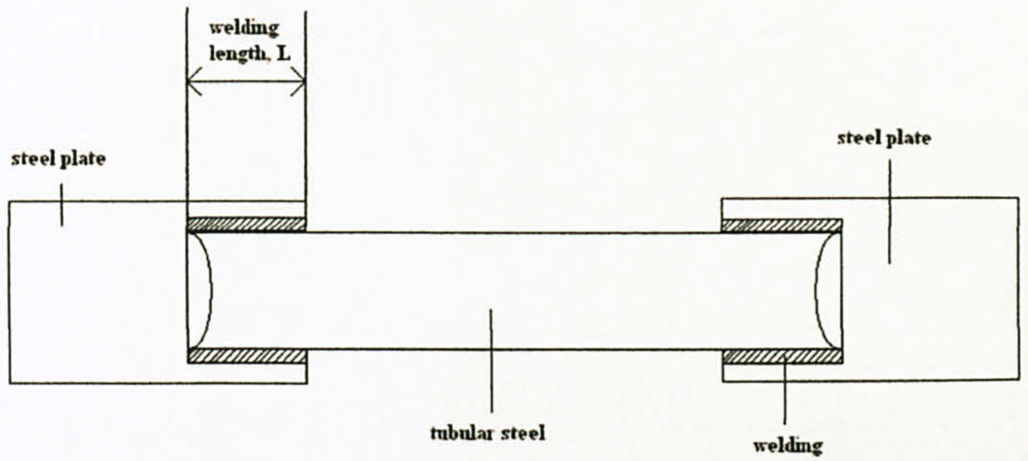
APPENDICES

APPENDIX A
DESIGN OF TUBULAR STEEL SAMPLE

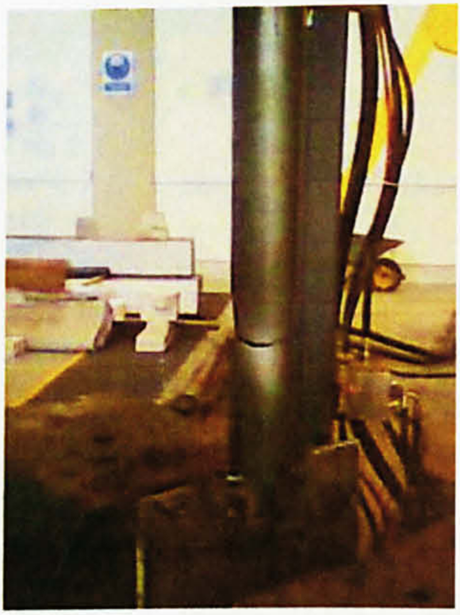
Recommended design of tubular steel welded to steel plate for tensile strength test sample. Details of the sample are shown in Figure 1.



APPENDIX B

FAILURE OF TUBULAR STEEL UNDER TENSILE STRENGTH

Test sample of tubular steel being tested using Universal Testing Machine



Failure at the midsection of the tubular steel

Necking failure at the middle section of the tubular steel

View of the failed fabricated sample under maximum tensile strength

Failure of grout-filled tubular steel. No slippage of grout from the tubular steel.

APPENDIX C

LOAD VS STROKE TABLE FOR PULL-OUT TEST OF GROUT-FILLED TUBULAR STEEL

40.3mm diameter – hollowed tubular steel (control)

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
4.835	0.029	88.935	1.164	126.11	2.295
7.648	0.055	89.049	1.192	126.767	2.321
10.157	0.083	89.211	1.218	127.492	2.349
12.831	0.11	91.314	1.241	125.205	2.378
15.452	0.137	91.619	1.267	127.037	2.403
17.803	0.163	91.338	1.294	128.233	2.429
20.453	0.189	91.44	1.32	128.933	2.454
22.977	0.217	94.015	1.346	129.407	2.48
25.529	0.244	94.231	1.374	124.913	2.513
28.018	0.272	94.435	1.406	126.974	2.538
30.52	0.298	96.679	1.429	128.706	2.565
32.933	0.325	96.614	1.455	126.56	2.595
35.168	0.351	98.767	1.482	128.844	2.619
37.497	0.376	98.797	1.509	130.366	2.646
39.698	0.403	100.662	1.533	131.099	2.672
42.022	0.431	100.416	1.561	131.685	2.699
44.316	0.457	102.469	1.587	132.107	2.726
46.548	0.484	102.782	1.618	132.526	2.753
48.655	0.514	103.015	1.647	132.885	2.78
50.561	0.544	104.736	1.676	133.25	2.809
52.7	0.57	106.523	1.699	133.553	2.834
54.85	0.594	105.793	1.729	133.84	2.862
56.959	0.62	107.979	1.753	134.092	2.89
59.084	0.644	109.695	1.779	134.302	2.915
61.611	0.673	108.712	1.806	134.467	2.943
63.953	0.7	110.936	1.832	134.611	2.969
66.182	0.726	112.494	1.855	134.729	2.999
68.206	0.754	111.54	1.887	134.823	3.025
70.211	0.775	113.9	1.915	134.884	3.053
72.431	0.802	115.574	1.943	134.908	3.08
74.716	0.829	113.898	1.97	134.879	3.106
77.033	0.859	116.345	1.999	134.885	3.135
79.229	0.887	118.031	2.023	134.9	3.163
81.1	0.913	119.257	2.048	134.958	3.189
82.136	0.943	117.202	2.078	135.029	3.215
83.809	0.97	119.76	2.105	135.097	3.245
84.626	0.995	121.415	2.131	135.168	3.271
85.19	1.026	122.739	2.161	135.248	3.3
85.666	1.054	123.906	2.19	135.322	3.326
86.115	1.082	121.951	2.219	135.404	3.351
87.108	1.111	123.914	2.244	135.498	3.379
88.287	1.138	125.254	2.271	135.575	3.406

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
135.682	3.434	140.691	5.334	141.475	7.481
135.79	3.462	140.933	5.361	141.485	7.51
135.898	3.487	140.991	5.386	141.482	7.586
136.198	3.79	141.046	5.414	141.495	7.614
136.402	3.814	141.104	5.438	141.543	7.721
136.514	3.839	141.173	5.465	141.543	7.803
136.608	3.864	141.268	5.491	141.59	7.828
136.72	3.889	141.329	5.518	141.619	7.857
136.869	3.918	141.404	5.547	141.644	7.883
136.984	3.943	141.548	5.631	141.67	7.912
137.089	3.973	141.604	5.712	141.69	7.938
137.18	4	141.658	5.738	141.728	7.964
137.265	4.029	141.712	5.766	141.762	7.992
137.35	4.058	141.771	5.794	141.796	8.019
137.434	4.087	141.892	5.905	141.844	8.046
137.513	4.112	141.918	5.932	141.878	8.073
137.614	4.14	141.936	5.959	141.906	8.099
137.721	4.168	142.009	6.038	141.939	8.127
137.811	4.195	142.035	6.066	141.96	8.155
137.914	4.221	142.029	6.092	141.982	8.181
138.025	4.249	142.068	6.2	142.012	8.209
138.122	4.277	142.074	6.228	142.022	8.235
138.21	4.304	142.088	6.255	142.019	8.265
138.3	4.331	142.109	6.282	142.345	8.563
138.398	4.357	142.125	6.31	142.355	8.577
138.474	4.383	142.138	6.336	142.377	8.59
138.572	4.411	142.124	6.389	142.392	8.604
138.665	4.436	142.095	6.418	142.409	8.615
138.752	4.463	142.078	6.444	142.43	8.63
138.846	4.489	142.048	6.469	142.443	8.645
138.945	4.518	142.008	6.497	142.45	8.656
139.03	4.545	141.953	6.526	142.469	8.67
139.114	4.571	141.901	6.553	142.486	8.683
139.19	4.599	141.846	6.58	142.5	8.697
139.271	4.626	141.783	6.61	142.516	8.709
139.362	4.654	141.705	6.635	142.53	8.725
139.436	4.681	141.644	6.664	142.546	8.735
139.521	4.707	141.579	6.689	142.56	8.75
139.598	4.733	141.543	6.719	142.73	8.899
139.683	4.762	141.532	6.748	142.737	8.912
139.765	4.788	141.416	6.886	142.747	8.926
139.835	4.817	141.391	6.912	142.761	8.941
139.89	4.844	141.387	6.939	142.774	8.955
139.976	4.871	141.377	6.967	142.789	8.969
140.046	4.897	141.372	6.993	142.802	8.98
140.14	4.923	141.369	7.022	142.817	8.996
140.217	4.949	141.366	7.126	142.91	9.063
140.292	4.978	141.362	7.209	142.921	9.077
140.373	5.003	141.459	7.372	142.932	9.091
140.46	5.03	141.462	7.398	142.939	9.105
140.551	5.059	141.471	7.427	142.942	9.117
140.644	5.087	141.469	7.455	143.038	9.296

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
143.06	9.312	145.077	10.443	147.165	13.304
143.075	9.326	145.647	12.139	147.18	13.316
143.082	9.34	145.729	12.154	147.196	13.33
143.099	9.353	145.776	12.165	147.212	13.343
143.111	9.364	145.812	12.178	147.227	13.357
143.131	9.378	145.848	12.191	147.25	13.37
143.148	9.393	145.872	12.206	147.269	13.385
143.237	9.472	146.036	12.326	147.285	13.399
143.244	9.486	146.044	12.341	147.427	13.518
143.251	9.499	146.058	12.355	147.431	13.533
143.258	9.515	146.069	12.367	147.445	13.547
143.253	9.527	146.084	12.381	147.471	13.56
143.249	9.54	146.098	12.394	147.501	13.575
143.236	9.555	146.109	12.407	147.526	13.589
143.23	9.57	146.124	12.42	147.545	13.602
143.313	9.634	146.138	12.436	147.571	13.615
143.356	9.649	146.154	12.449	147.598	13.63
143.409	9.662	146.173	12.46	147.619	13.645
143.46	9.676	146.289	12.571	147.631	13.66
143.502	9.689	146.306	12.585	147.716	13.756
143.55	9.703	146.32	12.599	147.727	13.769
143.596	9.717	146.338	12.612	147.738	13.784
143.986	9.876	146.35	12.627	147.749	13.798
144.017	9.891	146.362	12.639	147.77	13.813
144.046	9.905	146.38	12.653	147.781	13.826
144.071	9.917	146.401	12.665	147.793	13.839
144.104	9.931	146.414	12.68	147.805	13.854
144.13	9.945	146.502	12.75	147.882	13.937
144.157	9.959	146.512	12.764	147.896	13.95
144.18	9.972	146.526	12.778	147.912	13.963
144.206	9.986	146.544	12.789	147.928	13.976
144.228	10	146.555	12.804	147.943	13.99
144.256	10.011	146.572	12.817	147.962	14.004
144.278	10.026	146.591	12.83	147.972	14.017
144.521	10.146	146.604	12.844	147.985	14.031
144.555	10.161	146.706	12.924	148.003	14.046
144.581	10.175	146.72	12.937	148.01	14.058
144.604	10.188	146.738	12.952	148.177	14.221
144.629	10.201	146.75	12.965	148.193	14.235
144.656	10.214	146.777	12.98	148.204	14.249
144.68	10.229	146.791	12.993	148.221	14.263
144.714	10.243	146.804	13.008	148.235	14.277
144.741	10.254	146.917	13.101	148.251	14.29
144.763	10.268	146.937	13.115	148.265	14.306
144.796	10.281	146.95	13.127	148.271	14.317
144.926	10.35	146.964	13.14	148.288	14.331
144.947	10.364	146.986	13.154	148.3	14.345
144.966	10.378	147.005	13.168	148.31	14.356
144.99	10.392	147.025	13.183	147.16	17.117
145.012	10.403	147.039	13.195	147.654	17.131
145.042	10.417	147.131	13.276	146.178	17.312
145.057	10.432	147.148	13.289	146.972	17.5

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
146.904	17.595	150.101	19.827	136.375	23.126
147.259	17.744	150.105	19.84	136.198	23.139
148.312	17.767	150.112	19.852	135.069	23.232
148.734	17.791	150.187	20.003	134.92	23.244
148.853	17.807	150.198	20.016	134.071	23.3
148.971	17.819	150.227	20.068	133.854	23.311
149.097	17.848	150.229	20.082	133.583	23.326
149.121	17.863	150.274	20.164	132.116	23.395
149.119	17.894	150.28	20.177	131.711	23.41
149.11	17.908	150.278	20.189	129.448	23.468
149.067	17.997	150.319	20.258	128.989	23.483
149.04	18.025	150.322	20.269	127.138	23.564
149.04	18.051	150.364	20.351	126.911	23.578
149.042	18.077	150.383	20.409	126.752	23.589
149.05	18.106	149.014	21.036	126.6	23.603
149.06	18.134	149.453	21.09	126.466	23.615
149.075	18.174	149.92	21.103	126.359	23.627
149.088	18.214	150.161	21.115	125.92	23.677
149.096	18.228	150.335	21.127	125.797	23.69
149.133	18.309	150.444	21.141	124.934	23.781
149.138	18.321	150.584	21.18	124.252	23.846
149.207	18.441	150.598	21.194	123.822	23.886
149.245	18.508	150.601	21.307	123.69	23.899
149.262	18.521	150.593	21.323	123.552	23.912
149.299	18.588	150.586	21.334	123.006	23.963
149.348	18.653	150.562	21.404	122.087	24.046
149.358	18.668	150.557	21.418	121.955	24.06
149.372	18.681	150.508	21.501	121.816	24.074
149.481	18.842	149.958	21.893	121.652	24.088
149.486	18.858	149.912	21.907	121.089	24.142
149.509	18.896	149.869	21.918	120.954	24.156
149.518	18.91	149.815	21.933	120.37	24.224
149.528	18.922	149.023	22.069	120.24	24.236
149.576	18.99	148.928	22.083	119.446	24.326
149.584	19.005	148.562	22.126	118.151	24.458
149.59	19.018	147.706	22.208	118.042	24.47
149.605	19.03	147.53	22.222	117.169	24.546
149.611	19.044	147.354	22.237	116.999	24.559
149.665	19.111	146.63	22.307	115.981	24.641
149.669	19.125	146.505	22.323	115.802	24.654
149.719	19.205	145.316	22.431	115.146	24.706
149.726	19.219	144.4	22.512	114.987	24.718
149.739	19.232	144.269	22.524	114.411	24.767
149.744	19.245	143.259	22.621	113.484	24.846
149.758	19.259	142.151	22.702	112.133	24.938
149.772	19.274	141.245	22.786	111.938	24.951
149.916	19.503	140.153	22.87	111.264	24.992
149.922	19.517	139.974	22.882	111.077	25.004
149.927	19.529	138.995	22.953	110.206	25.058
150.004	19.651	138.814	22.965	109.423	25.098
150.053	19.745	137.819	23.035	109.129	25.112
150.062	19.759	137.583	23.049	108.833	25.127

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
107.86	25.167	46.882	26.248
106.752	25.21	45.378	26.275
105.784	25.238	44.553	26.292
105.34	25.253	43.798	26.304
104.911	25.269	42.107	26.334
103.273	25.324	41.121	26.349
102.232	25.354	39.985	26.365
101.721	25.369	37.753	26.391
100.403	25.4	36.605	26.406
99.636	25.415	35.38	26.42
98.815	25.431	34.076	26.432
97.935	25.444	32.882	26.446
96.184	25.483	29.823	26.471
95.655	25.497	26.773	26.481
94.541	25.527	20.055	26.483
94.025	25.539	19.857	26.476
93.373	25.554	19.714	26.47
92.715	25.569	19.669	26.469
92.095	25.583		
91.419	25.596		
90.751	25.61		
90.059	25.626		
89.346	25.641		
88.592	25.657		
87.803	25.671		
87.111	25.684		
86.288	25.699		
85.567	25.713		
84.757	25.726		
83.935	25.739		
82.255	25.768		
81.485	25.78		
79.695	25.809		
78.733	25.824		
77.704	25.842		
74.394	25.881		
72.196	25.906		
69.21	25.933		
64.122	25.967		
60.12	25.998		
59.101	26.013		
57.232	26.043		
56.448	26.057		
55.077	26.084		
53.623	26.115		
52.95	26.126		
51.497	26.154		
50.906	26.166		
49.619	26.192		
48.952	26.204		
47.596	26.234		

40.3mm diameter – grout-filled tubular steel (1)

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
55.134	0.531	142.354	7.775	128.792	21.261
66.041	0.669	144.878	7.911	122.61	21.402
69.922	0.835	145.16	8.052	119.644	21.538
72.752	0.979	145.932	8.45	115.784	21.676
77.762	1.12	146.188	8.591	110.622	21.818
82.58	1.239	146.439	8.732	106.095	21.958
89.728	1.395	147.169	9.151	102.028	22.08
95.993	1.532	147.403	9.291	96.68	22.242
102.291	1.669	147.64	9.432	91.552	22.384
104.052	1.812	148.894	10.273	86.73	22.506
105.308	1.934	149.083	10.413	80.582	22.648
111.227	2.072	149.265	10.556	72.923	22.789
116.915	2.21	149.422	10.675	69.233	22.924
123.082	2.368	149.599	10.816	66.465	23.06
127.365	2.486	149.77	10.957	63.546	23.197
131.634	2.625	150.664	11.782	57.139	23.338
135.084	2.764	150.802	11.923	58.804	23.477
137.301	2.907	150.937	12.063	56.045	23.618
138.105	3.049	151.083	12.225	53.169	23.763
138.283	3.172	151.2	12.367	50.511	23.906
138.432	3.314	151.314	12.506	47.981	24.03
138.436	3.457	151.414	12.646	44.473	24.171
138.283	3.599	151.84	13.204	40.971	24.313
138.1	3.74	151.932	13.344	36.076	24.457
137.986	3.88	152.014	13.481	30.729	24.601
137.955	4.02	152.091	13.622	26.039	24.763
137.964	4.14	152.948	15.407	22.554	24.904
138.038	4.278	153	15.547	18.996	25.048
138.16	4.418	153.033	15.687	15.799	25.167
138.292	4.556	153.072	15.829	10.948	25.311
138.478	4.716	153.114	15.969	3.104	25.453
138.628	4.855	153.38	17.358	2.22	25.589
138.816	4.993	153.394	17.497	1.43	25.707
139.003	5.134	153.401	17.639	0.075	25.845
139.237	5.273	153.409	17.778		
139.37	5.413	153.426	17.919		
139.595	5.553	153.445	18.48		
139.906	5.694	153.441	18.62		
140.223	5.832	153.442	18.741		
140.046	5.974	153.44	18.88		
140.713	6.113	153.325	19.722		
140.894	6.233	153.272	19.861		
141.276	6.374	153.191	20.001		
141.676	6.513	153.042	20.141		
142.046	6.655	152.726	20.281		
142.407	6.794	151.89	20.421		
142.74	6.934	149.011	20.565		
143.392	7.214	145.924	20.707		
143.715	7.354	142.262	20.851		
144.344	7.632	137.577	20.996		

40.3mm diameter – grout-filled tubular steel (2)

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
17.706	0.142	134.13	2.867	143.402	6.839
23.508	0.202	134.66	2.921	143.152	6.951
30.164	0.257	134.024	2.977	143.59	6.999
35.799	0.312	134.594	3.026	143.701	7.053
41.096	0.366	135.424	3.082	144.346	7.325
46.133	0.421	135.621	3.137	144.466	7.372
50.413	0.469	135.665	3.185	144.61	7.43
55.407	0.523	135.715	3.241	144.734	7.487
60.331	0.58	135.765	3.298	145.418	7.818
64.891	0.636	135.933	3.458	145.522	7.865
69.064	0.691	136.015	3.515	145.949	8.083
73.125	0.748	136.1	3.569	146.058	8.139
75.223	0.798	136.451	3.842	146.171	8.196
77.44	0.856	136.592	3.897	146.277	8.251
77.978	0.913	136.727	3.952	146.392	8.307
78.921	0.972	136.889	4.007	146.889	8.58
80.824	1.025	137.066	4.063	146.996	8.636
82.503	1.072	137.228	4.118	147.087	8.683
84.703	1.126	137.361	4.167	147.188	8.74
86.967	1.181	137.52	4.223	147.283	8.795
87.653	1.234	137.679	4.278	147.923	9.171
90.437	1.29	137.822	4.334	148.019	9.227
92.713	1.345	137.915	4.382	148.111	9.283
94.364	1.394	138	4.438	148.204	9.338
96.003	1.45	136.076	4.497	148.274	9.386
100.275	1.503	137.772	4.552	148.36	9.443
102.495	1.557	138.152	4.608	148.441	9.498
104.26	1.612	138.289	4.664	148.683	9.666
105.565	1.668	138.534	4.88	148.963	10.092
109.498	1.723	138.505	4.936	149.197	10.149
110.988	1.778	138.558	4.983	149.249	10.206
113.408	1.824	138.69	5.039	149.292	10.254
115.629	1.878	138.85	5.095	149.643	10.583
116.043	1.935	139.043	5.152	149.696	10.639
118.512	1.991	139.23	5.312	149.761	10.689
117.232	2.04	139.944	5.534	149.816	10.746
121.136	2.093	140.135	5.582	149.881	10.801
121.513	2.15	140.33	5.637	149.946	10.858
120.625	2.208	140.524	5.693	150.281	11.179
124.56	2.262	141.023	5.851	150.336	11.235
125.241	2.318	141.186	5.909	150.605	11.508
124.417	2.374	141.37	5.965	150.65	11.565
127.716	2.42	142.121	6.239	150.697	11.614
129.126	2.477	142.268	6.296	150.746	11.668
127.298	2.536	142.399	6.353	150.933	11.892
130.862	2.59	142.49	6.401	150.981	11.948
130.154	2.65	142.589	6.457	151.027	12.005
132.357	2.705	142.688	6.504	151.24	12.269
130.88	2.757	143.14	6.728	151.278	12.324
133.355	2.811	143.26	6.776	151.316	12.38

Actuator: 1 Channel:0 A1 Load : *Current (kN)*	Actuator: 1 Channel:1 A1 Stroke : *Current (mm)*	Actuator: 1 Channel:0 A1 Load : *Current (kN)*	Actuator: 1 Channel:1 A1 Stroke : *Current (mm)*	Actuator: 1 Channel:0 A1 Load : *Current (kN)*	Actuator: 1 Channel:1 A1 Stroke : *Current (mm)*
151.357	12.436	152.585	19.452	69.272	24.2
151.506	12.654	152.542	19.725	68.125	24.255
151.605	12.815	152.529	19.78	67.282	24.302
151.637	12.872	152.52	19.836	66.03	24.36
151.674	12.927	152.511	19.892	64.777	24.417
151.858	13.255	152.499	19.948	63.812	24.473
152.147	13.909	152.417	20.268	62.817	24.529
152.169	13.957	152.403	20.325	62.042	24.578
152.192	14.013	152.361	20.493	61.202	24.633
152.215	14.068	152.347	20.549	60.297	24.69
152.337	14.396	152.288	20.766	59.318	24.747
152.385	14.556	152.265	20.822	58.374	24.804
152.406	14.612	152.248	20.869	57.555	24.85
152.422	14.669	152.103	21.245	56.583	24.906
152.476	14.885	152.037	21.404	55.604	24.954
152.494	14.942	151.8	21.782	54.741	25.009
152.535	15.158	151.757	21.837	53.762	25.063
152.552	15.214	151.701	21.894	52.786	25.093
152.567	15.271	151.652	21.941		
152.578	15.327	151.595	21.997		
152.642	15.647	150.95	22.373		
152.65	15.704	150.801	22.43		
152.656	15.759	150.618	22.479		
152.711	16.088	149.91	22.639		
152.719	16.144	149.551	22.696		
152.721	16.195	149.154	22.753		
152.749	16.466	148.693	22.811		
152.752	16.522	148.166	22.867		
152.755	16.579	147.528	22.924		
152.75	16.633	146.89	22.972		
152.75	16.692	145.98	23.03		
152.763	16.907	134.48	23.1		
152.766	16.955	116.632	23.157		
152.763	17.013	111.499	23.208		
152.768	17.284	106.958	23.26		
152.77	17.34	102.659	23.314		
152.768	17.396	98.796	23.363		
152.764	17.453	96.394	23.419		
152.765	17.717	94.646	23.474		
152.759	17.773	92.09	23.532		
152.756	17.83	89.149	23.589		
152.743	18.157	87.043	23.639		
152.734	18.213	84.466	23.696		
152.736	18.262	82.489	23.744		
152.706	18.534	80.65	23.803		
152.705	18.591	78.605	23.86		
152.698	18.644	76.635	23.916		
152.687	18.701	74.821	23.974		
152.655	18.973	73.433	24.029		
152.648	19.029	72.193	24.085		
152.591	19.404	70.751	24.142		

60.3mm diameter – hollowed tubular steel (control)

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
7.736	0.082	104.321	1.523	138.283	7.339
10.026	0.107	105.257	1.606	138.679	7.396
12.355	0.134	108.299	1.632	138.074	8.543
14.708	0.161	107.523	1.658	138.065	8.573
16.736	0.189	110.455	1.683	137.898	8.6
19.375	0.216	111.523	1.823	137.699	8.629
21.44	0.239	113.99	1.879	138.467	8.652
23.854	0.267	112.643	1.909	138.263	8.679
26.202	0.294	115.468	1.935	137.98	8.709
28.511	0.321	115.329	2.015	138.248	8.736
30.823	0.349	117.842	2.041	138.668	8.763
33.083	0.374	115.54	2.07	139.09	8.79
35.352	0.402	116.985	2.178	138.986	8.818
37.651	0.428	119.804	2.204	139.278	8.841
40.109	0.455	118.535	2.235	138.796	8.869
42.525	0.483	120.57	2.261	139.299	8.899
44.92	0.511	120.015	2.29	139.777	8.925
47.252	0.54	121.283	2.477	139.127	8.953
49.205	0.561	122.423	2.532	139.492	8.98
51.748	0.594	122.264	2.671	139.737	13.361
53.479	0.618	125.182	2.694	139.778	13.384
55.436	0.647	123.359	2.723	139.801	13.413
57.342	0.675	126.261	3.163	139.855	13.441
59.251	0.702	126.079	3.301	139.712	13.465
61.017	0.725	127.189	3.407	139.689	13.493
63.4	0.753	127.773	3.462	139.828	13.522
65.846	0.781	128.259	4.282	139.816	13.549
68.296	0.808	128.333	4.39	139.611	13.577
70.699	0.837	130.423	4.444	139.717	13.604
72.994	0.865	131.434	4.524	139.596	13.634
73.321	0.893	130.631	4.553	139.461	13.661
75.995	0.922	131.046	4.69	139.336	13.689
78.486	0.948	130.052	4.717	139.315	13.712
79.168	0.975	131.836	4.801	139.36	13.741
81.861	1.001	131.525	4.828	139.267	13.77
84.42	1.027	132.789	4.906	139.155	13.798
86.973	1.054	132.283	4.935	138.785	14.698
89.487	1.082	134.256	5.178	138.89	14.726
84.084	1.111	134.837	5.344	138.861	14.754
87.287	1.138	134.517	5.372	138.878	14.782
90.232	1.164	134.127	5.402	138.176	15.329
92.92	1.192	134.544	5.701	138.139	15.354
95.522	1.217	134.517	5.73	138.024	15.381
92.419	1.25	134.422	5.758	138.004	15.411
95.495	1.276	137.069	6.99	137.916	15.44
98.214	1.302	138.134	7.016	137.377	15.633
95.217	1.335	137.864	7.205	137.061	15.823
98.021	1.358	138.097	7.233	137.048	15.851
100.937	1.384	137.546	7.262	136.963	15.879
103.503	1.41	138.334	7.288	136.846	15.907

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
136.738	15.936	124.672	21.325	116.8	24.939
136.646	15.962	123.058	21.792	116.335	25.238
135.412	16.971	123.008	21.816	116.272	25.267
135.327	17.004	122.958	21.843	116.191	25.295
135.266	17.031	122.902	21.871	116.11	25.32
135.205	17.056	122.854	21.899	116.022	25.348
135.15	17.083	122.816	21.928	115.922	25.377
134.181	17.497	122.786	21.956	115.831	25.405
132.256	17.963	122.119	22.475	115.732	25.433
132.123	17.992	122.053	22.5	115.022	25.656
131.992	18.021	122.001	22.528	114.963	25.68
131.919	18.046	121.444	22.807	114.89	25.709
131.849	18.073	121.392	22.83	114.833	25.736
131.798	18.1	121.295	22.859	114.778	25.763
131.744	18.128	121.193	22.887	114.724	25.791
131.677	18.156	121.125	22.916	114.645	25.819
131.618	18.183	121.047	22.944	114.161	26.198
131.585	18.207	120.972	22.973	114.14	26.226
131.56	18.233	120.904	23.002	113.518	26.58
131.546	18.263	120.864	23.026	113.418	26.607
131.531	18.291	120.818	23.054	113.327	26.632
131.518	18.318	120.736	23.082	113.22	26.661
130.629	18.943	120.648	23.11	112.82	26.804
130.563	18.97	119.247	23.486	112.734	26.831
130.476	18.999	119.101	23.514	112.194	27.05
129.923	19.189	118.982	23.54	112.093	27.078
129.854	19.218	118.892	23.569	111.995	27.108
129.788	19.246	118.812	23.596	111.91	27.136
129.695	19.274	118.763	23.624	111.821	27.165
127.326	19.802	118.684	23.653	111.728	27.189
127.227	19.831	118.623	23.677	111.642	27.217
127.138	19.855	118.549	23.703	111.54	27.245
127.062	19.882	118.496	23.732	110.018	28.056
126.963	19.911	118.466	23.759	110.025	28.084
126.82	19.939	118.415	23.788	110.02	28.112
126.065	20.522	118.362	23.813	110.013	28.141
126.051	20.552	118.305	23.839	109.984	28.166
126.028	20.579	118.014	24.198	109.972	28.193
126.001	20.606	117.991	24.221	109.974	28.223
125.969	20.631	117.961	24.251	109.953	28.248
125.952	20.663	117.949	24.278	109.63	28.442
125.922	20.693	117.921	24.308	109.555	28.47
125.86	20.715	117.213	24.665	109.485	28.499
125.822	20.745	117.171	24.692	109.421	28.526
125.151	21.103	117.131	24.717	109.332	28.555
125.107	21.13	117.093	24.745	109.275	28.579
125.055	21.16	117.043	24.774	109.2	28.607
124.992	21.184	116.979	24.8	109.102	28.636
124.93	21.212	116.926	24.829	108.282	29.044
124.87	21.24	116.888	24.854	108.259	29.072
124.813	21.269	116.856	24.881	108.241	29.1
124.743	21.297	116.819	24.91	108.216	29.127

Actuator: 1 Channel:0 A1 Load : *Current (kN)*	Actuator: 1 Channel:1 A1 Stroke : *Current (mm)*
108.167	29.157
108.14	29.179
108.102	29.208
108.036	29.237
108.004	29.266
107.973	29.294
107.937	29.322
107.882	29.35
106.859	29.781
106.845	29.81
106.822	29.837
105.145	30.962
105.108	30.989
105.093	31.017
105.073	31.046
105.044	31.076
104.567	31.322
104.504	31.347
104.429	31.378
104.388	31.404
103.932	31.647
103.901	31.671
103.864	31.699
103.828	31.728
103.804	31.755
103.649	32.19
103.652	32.214
103.644	32.24
103.643	32.268
103.648	32.295
103.658	32.322
103.656	32.35
103.628	32.379
103.582	32.407
103.529	32.431
103.471	32.458
103.417	32.487
103.377	32.515
103.337	32.538
102.616	32.788
102.553	32.817
102.493	32.84
102.427	32.874
102.391	32.898
102.347	32.926
102.305	32.954
101.903	33.233
101.119	34.051
101.111	34.073
101.097	34.103
101.097	34.13

Actuator: 1 Channel:0 A1 Load : *Current (kN)*	Actuator: 1 Channel:1 A1 Stroke : *Current (mm)*
101.107	34.16
101.098	34.187
101.039	34.296
101.026	34.319
101.015	34.347
100.891	34.487
100.844	34.516
100.806	34.539
100.716	34.623
100.681	34.652
100.64	34.68
99.001	34.708
98.978	34.732
95.879	34.761
91.232	34.788
89.576	34.815
87.883	34.842
81.243	34.866
80.98	34.895
56.676	34.921
54.98	34.95
52.322	34.977
48.322	35.007
46.789	35.03
45.557	35.057
43.879	35.086
40.844	35.552
37.165	35.964
36.88	35.991
36.223	36.019
36.134	36.042
36.05	36.077
35.978	36.104
34.869	36.127
34.501	36.155
33.878	36.178
33.214	36.207
33.112	36.233
32.988	36.258
32.839	36.287
32.543	36.313
32.119	36.329
32.001	36.333
31.122	36.335
30.011	36.335

60.3mm diameter – grout-filled tubular steel (1)

Actuator: 1 Channel:0 A1 Load : Current (kN)	Actuator: 1 Channel:1 A1 Stroke : Current (mm)	Actuator: 1 Channel:0 A1 Load : Current (kN)	Actuator: 1 Channel:1 A1 Stroke : Current (mm)	Actuator: 1 Channel:0 A1 Load : Current (kN)	Actuator: 1 Channel:1 A1 Stroke : Current (mm)
19.411	0.154	144.837	2.878	119.254	5.609
25.454	0.208	145.731	2.932	119.143	5.655
31.395	0.262	146.474	2.98	118.937	5.711
37.008	0.316	147.454	3.034	119.036	5.768
42.527	0.371	148.218	3.089	119.357	5.813
48.046	0.425	148.732	3.138	119.918	5.869
53.509	0.48	149.072	3.194	118.978	7.386
58.844	0.534	149.255	3.25	118.89	7.442
63.983	0.59	149.22	3.306	118.869	7.5
66.385	0.647	148.763	3.363	118.9	7.546
67.93	0.696	148.463	3.412	118.791	7.602
71.6	0.751	147.657	3.47	118.654	7.659
74.514	0.806	145.485	3.527	118.653	7.714
77.136	0.861	142.634	3.587	118.781	7.769
79.762	0.917	140.4	3.644	118.945	7.817
82.249	0.97	139.394	3.693	117.717	9.394
84.6	1.026	138.613	3.748	117.549	9.451
86.872	1.079	138.41	3.804	117.448	9.508
89.102	1.135	138.643	3.857	117.26	9.563
90.966	1.182	139.021	3.904	117.218	9.611
93.2	1.238	139.522	3.958	117.093	9.668
95.374	1.294	140.19	4.012	117.131	9.724
97.522	1.349	140.854	4.066	117.303	9.782
99.837	1.405	141.315	4.121	117.598	9.829
101.749	1.451	141.54	4.176	117.702	10.796
103.902	1.508	141.484	4.233	117.363	10.854
106.078	1.564	141.088	4.281	117.126	10.91
107.814	1.612	140.232	4.339	116.866	10.966
109.462	1.675	139.036	4.397	116.7	11.014
111.537	1.73	137.719	4.456	116.457	11.072
113.756	1.785	136.834	4.514	116.124	11.13
114.867	1.832	136.151	4.562	115.849	11.184
115.65	1.891	135.496	4.621	115.61	11.233
116.58	1.948	134.572	4.678	115.264	11.29
118.666	2.003	133.542	4.734	115.206	11.348
120.459	2.058	132.285	4.792	115.069	11.404
122.654	2.104	131.046	4.849	114.783	11.453
124.019	2.162	129.984	4.896	114.536	11.51
125.015	2.216	128.85	4.951	114.367	11.567
127.143	2.271	127.881	5.008	114.355	11.622
128.259	2.317	126.931	5.064	114.435	11.679
130.601	2.371	126.14	5.121	114.58	11.726
131.926	2.429	125.462	5.175	114.837	11.781
133.546	2.476	124.622	5.225	114.892	12.693
135.335	2.536	123.646	5.279	114.693	12.749
137.261	2.594	122.72	5.336	114.448	12.808
139.234	2.651	121.659	5.391	114.158	12.864
140.847	2.71	120.6	5.448	113.918	12.921
142.347	2.766	119.918	5.495	113.642	12.97
143.617	2.821	119.458	5.552	113.318	13.027

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
113.126	13.084	109.49	20.938	105.034	29.03
112.922	13.132	109.38	20.994	104.803	29.087
112.73	13.188	109.189	21.052	104.627	29.144
112.604	13.239	109.057	21.107	104.476	29.2
112.513	13.296	108.903	21.156	104.377	29.257
112.338	13.351	108.724	21.214	104.389	29.304
112.269	13.407	108.679	21.269	104.523	29.361
112.166	13.463	108.74	21.327	104.672	29.416
112.161	13.518	108.841	21.382	104.621	30.775
112.24	13.573	108.796	22.626	104.419	30.822
112.416	13.621	108.588	22.681	104.222	30.88
112.603	13.675	108.428	22.739	103.98	30.935
112.911	13.731	108.234	22.795	103.765	30.985
112.483	14.704	108.076	22.852	103.496	31.042
112.349	14.761	107.983	22.899	103.255	31.098
112.248	14.82	107.775	22.956	103.039	31.154
112.144	14.868	107.567	23.013	102.773	31.209
112.027	14.924	107.406	23.071	102.663	31.258
111.727	14.981	107.278	23.118	102.646	31.314
111.494	15.037	107.09	23.176	102.762	31.371
111.36	15.093	106.99	23.233	102.851	31.427
111.235	15.15	107.068	23.288	102.679	33.16
111.198	15.199	107.247	23.337	102.48	33.215
111.124	15.255	107.437	23.393	102.25	33.273
111.022	15.31	107.724	23.449	102.071	33.32
110.956	15.36	107.821	25.024	101.882	33.376
110.932	15.416	107.584	25.08	101.802	33.432
110.946	15.471	107.418	25.136	101.814	33.48
110.738	17.207	107.246	25.192	101.894	33.536
110.575	17.254	107.235	25.239	100.878	35.389
110.431	17.311	107.306	25.296	100.781	35.436
110.359	17.368	107.378	25.353	100.795	35.493
110.288	17.425	107.531	25.407	100.879	35.55
110.332	17.48	107.74	25.454	100.837	37.377
110.402	17.528	107.709	26.544	100.522	37.434
110.658	17.582	107.512	26.6	100.341	37.482
110.97	17.637	107.263	26.657	100.225	37.537
110.706	18.882	107.063	26.712	100.179	37.596
110.551	18.937	106.89	26.771	100.207	37.652
110.344	18.995	106.759	26.819	100.357	37.7
110.218	19.053	106.591	26.875	100.64	37.757
110.163	19.099	106.321	26.932	100.899	37.811
110.116	19.157	105.991	26.987	99.32	38.959
110.039	19.214	105.775	27.035	97.457	38.971
109.96	19.27	105.578	27.094	96.015	38.976
109.871	19.318	105.428	27.15	95.35	38.978
109.86	19.374	105.314	27.207	95.321	38.978
109.84	19.431	105.355	27.261	95.298	38.978
109.912	19.487	105.514	27.311	95.234	38.977
109.705	20.775	105.786	27.367	94.942	38.976
109.585	20.833	105.486	28.926	94.772	38.976
109.555	20.882	105.23	28.984	93.738	38.975

Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)
92.526	38.976
90.572	38.976
89.902	38.975
88.586	38.975
87.452	38.976
86.426	38.976
82.985	38.975
80.017	38.976
78.543	38.976
76.934	38.976
75.892	38.976
71.375	38.977
70.053	38.977
68.825	38.978
66.231	38.977
65.98	38.979
62.332	38.979
60.016	38.979
58.912	38.979
55.678	38.978
54.897	38.979

60.3mm diameter – grout-filled tubular steel (2)

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
10.61	0.092	129.324	2.812	147.83	5.529
15.999	0.145	129.358	2.862	147.831	5.583
21.943	0.209	130.976	2.919	147.92	5.639
26.751	0.265	131.164	2.982	148.535	5.688
30.532	0.313	132.116	3.029	149.134	5.742
34.771	0.377	131.728	3.086	148.977	5.799
38.067	0.422	134.073	3.139	148.118	5.856
42.352	0.477	132.477	3.196	149.327	5.903
46.517	0.533	135.796	3.25	149.284	5.959
50.22	0.587	133.601	3.308	149.58	6.015
53.775	0.641	135.463	3.357	149.628	6.064
56.942	0.687	136.552	3.414	149.681	6.119
61.089	0.744	138.046	3.468	149.704	6.176
65.115	0.797	138.598	3.515	149.679	6.232
69.075	0.853	138.756	3.58	149.659	6.281
72.275	0.9	138.705	3.629	149.634	6.338
75.712	0.954	138.672	3.685	149.614	6.386
77.725	1.019	140.71	3.74	149.539	6.442
80.341	1.066	139.526	3.796	149.434	6.498
83.759	1.12	139.653	3.853	149.189	6.555
87.247	1.183	141.857	3.908	148.718	6.604
90	1.229	139.913	3.958	146.741	6.661
93.262	1.287	140.455	4.011	140.229	6.723
92.38	1.336	141.82	4.066	141.024	6.776
93.959	1.393	141.465	4.123	141.257	6.831
96.696	1.449	141.431	4.177	142.34	6.876
97.872	1.505	144.148	4.233	142.947	6.93
100.365	1.559	143.356	4.282	143.3	6.984
101.429	1.617	143.745	4.336	143.489	7.047
102.38	1.674	145.077	4.393	142.729	7.104
103.354	1.721	145.5	4.449	142.044	7.152
105.561	1.776	143.354	4.508	142.112	7.207
106.427	1.831	144.622	4.556	142.54	7.256
107.513	1.887	145.687	4.611	140.702	7.314
108.27	1.936	146.13	4.659	139.114	7.378
110.646	1.989	145.322	4.716	137.857	7.427
110.461	2.047	145.376	4.771	127.972	7.491
112.919	2.101	146.579	4.827	127.049	7.54
113.625	2.156	146.896	4.882	126.666	7.592
115.419	2.202	147.322	4.929	125.866	7.644
115.287	2.259	146.61	4.985	125.872	7.695
117.892	2.319	146.574	5.041	124.349	7.751
118.456	2.369	146.203	5.097	123.667	7.797
118.804	2.426	147.507	5.154	124.757	7.85
120.019	2.483	146.847	5.209	124.39	7.905
121.684	2.538	147.991	5.264	125.319	7.95
123.921	2.592	147.139	5.313	125.77	8.003
124.814	2.648	147.339	5.376	125.19	8.057
126.687	2.703	147.53	5.424	125.519	8.11
127.536	2.758	148.262	5.479	126.124	8.155

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
125.589	8.207	75.601	11.03	75.209	11.8
125.794	8.261	75.715	11.086	75.22	11.801
126.355	8.319	75.841	11.135	75.246	11.802
125.208	8.374	75.974	11.19	75.266	11.802
123.227	8.424	76.091	11.238	75.282	11.804
107.618	8.49	76.246	11.296	75.302	11.803
106.398	8.544	76.407	11.352	75.331	11.803
104.78	8.598	76.532	11.4	75.352	11.805
102.864	8.648	76.619	11.457	75.371	11.805
98.001	8.706	76.749	11.511	75.372	11.804
65.898	8.782	76.9	11.568	75.38	11.806
66.836	8.829	77.03	11.617	75.378	11.806
67.2	8.872	77.212	11.68	75.379	11.806
67.463	8.924	77.234	11.726	75.386	11.807
67.78	8.979	76.778	11.758	75.396	11.807
68.03	9.033	76.442	11.773	75.401	11.807
68.043	9.088	76.201	11.779	75.409	11.806
66.816	9.138	75.971	11.783	75.424	11.808
69.076	9.191	75.717	11.784	75.428	11.807
70.594	9.238	75.55	11.785	75.447	11.808
71.029	9.293	75.435	11.785	75.459	11.808
71.199	9.348	75.358	11.786	75.467	11.808
71.287	9.405	75.307	11.788	75.475	11.809
71.375	9.455	75.212	11.788	75.482	11.809
71.475	9.51	75.144	11.787	75.486	11.81
71.627	9.565	75.14	11.787	75.487	11.81
71.772	9.622	75.165	11.788	75.489	11.811
71.844	9.67	75.157	11.789	75.489	11.81
71.947	9.727	75.154	11.789	75.486	11.811
72.064	9.783	75.169	11.791	75.483	11.811
72.178	9.839	75.197	11.791	75.48	11.81
72.297	9.888	75.228	11.793	75.48	11.811
72.405	9.943	75.246	11.792	75.48	11.81
72.383	9.999	75.27	11.793	75.471	11.811
72.493	10.056	75.282	11.795	75.466	11.812
72.707	10.111	75.295	11.796	75.459	11.81
72.925	10.158	75.318	11.796	75.464	11.812
73.178	10.214	75.328	11.796	75.47	11.812
73.366	10.27	75.342	11.797	75.466	11.811
73.549	10.326	75.355	11.798	75.474	11.811
73.718	10.372	75.361	11.798	75.475	11.811
73.874	10.429	75.366	11.798	75.48	11.814
74.062	10.486	75.376	11.799	75.483	11.812
74.234	10.54	75.397	11.799	75.478	11.812
74.397	10.589	75.378	11.8	75.481	11.813
74.563	10.645	75.337	11.801	75.476	11.812
74.709	10.694	75.304	11.799	75.474	11.813
74.888	10.758	75.277	11.801	75.471	11.813
75.052	10.814	75.258	11.801	75.462	11.813
75.171	10.862	75.231	11.799	75.453	11.813
75.321	10.918	75.219	11.801		
75.482	10.974	75.212	11.801		

60.3mm diameter – grout-filled tubular steel (3)

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
20.587	0.161	145.582	2.843	155.756	7.797
26.306	0.215	147.521	2.898	155.887	7.851
31.672	0.28	147.93	2.946	156.026	7.908
37.47	0.334	148.146	3.002	156.155	7.964
42.354	0.389	148.289	3.058	156.309	8.02
47.046	0.444	148.394	3.113	156.454	8.075
51.404	0.499	148.483	3.168	156.6	8.131
55.662	0.555	148.553	3.225	156.765	8.187
59.243	0.601	148.6	3.281	156.905	8.235
63.382	0.654	148.602	3.338	157.069	8.292
67.554	0.709	148.602	3.499	157.768	8.565
71.079	0.755	148.732	3.77	158.576	8.893
75.117	0.811	148.805	3.827	158.688	8.942
78.941	0.866	148.877	3.882	158.831	8.995
76.816	0.928	148.943	3.937	159.357	9.219
80.783	0.982	149.022	3.994	159.487	9.276
84.233	1.035	148.422	4.041	159.616	9.331
87.598	1.09	148.839	4.097	159.715	9.379
91.002	1.144	149.199	4.154	159.835	9.435
94.352	1.198	149.278	4.208	159.955	9.49
97.477	1.254	149.344	4.265	160.078	9.546
97.741	1.313	149.695	4.479	160.649	9.817
99.413	1.371	149.775	4.529	159.679	9.874
101.87	1.428	149.851	4.584	160.666	9.93
104.321	1.475	149.494	4.639	160.974	9.985
107.109	1.529	149.954	4.694	161.072	10.033
109.913	1.585	150.231	4.91	161.179	10.09
112.724	1.64	150.301	4.966	161.279	10.147
115.541	1.694	150.375	5.021	161.892	10.476
117.883	1.742	150.452	5.081	161.989	10.532
120.557	1.795	150.504	5.138	162.097	10.588
123.267	1.861	150.845	5.518	162.193	10.646
124.622	1.911	150.944	5.574	162.285	10.701
127.217	1.967	151.01	5.621	162.386	10.756
129.913	2.022	151.048	5.677	162.856	11.027
132.246	2.078	151.116	5.732	162.047	11.082
134.286	2.133	152.598	6.602	162.69	11.133
134.93	2.19	152.677	6.656	163.102	11.188
136.235	2.247	151.12	6.714	163.198	11.242
138.649	2.3	152.868	6.769	163.274	11.297
140.06	2.347	153.112	6.825	163.354	11.345
141.342	2.402	153.167	6.881	163.676	11.561
141.055	2.459	153.986	7.096	163.757	11.617
143.122	2.514	154.223	7.47	163.835	11.674
143.234	2.57	155.105	7.525	163.915	11.728
144.916	2.624	155.276	7.581	164.002	11.784
145.872	2.681	155.403	7.638	164.561	12.176
146.499	2.73	155.529	7.693	164.626	12.226
147.116	2.784	155.63	7.74	164.695	12.28

Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1	Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)	A1 Load : Current (kN)	A1 Stroke : Current (mm)
164.777	12.336	168.868	17.132	170.242	24.736
164.833	12.385	168.952	17.301	170.214	25.344
164.907	12.441	169.049	17.518	170.175	25.888
164.98	12.497	169.122	17.685	170.155	25.937
165.045	12.551	169.268	18.012	170.123	26.382
165.121	12.606	169.291	18.068	170.118	26.43
165.458	12.88	169.304	18.117	170.09	26.712
165.525	12.937	169.332	18.173	170.074	26.871
165.582	12.984	169.409	18.389	170.001	27.25
165.658	13.04	169.473	18.612	169.992	27.306
165.721	13.096	169.482	18.66	169.985	27.361
165.908	13.266	169.534	18.773	169.95	27.531
165.972	13.321	169.588	18.932	169.946	27.588
166.03	13.377	169.603	18.987	169.918	27.636
166.081	13.434	169.624	19.045	169.91	27.692
166.313	13.649	169.674	19.212	169.898	27.749
166.371	13.705	169.69	19.27	169.85	27.917
166.429	13.761	169.708	19.318	169.83	27.972
166.482	13.821	169.815	19.815	169.769	28.188
166.539	13.874	169.837	19.871	169.746	28.244
166.75	14.089	169.851	19.926	169.731	28.301
166.796	14.145	169.878	20.087	169.71	28.357
166.843	14.191	169.937	20.415	169.63	28.518
166.893	14.248	169.951	20.469	169.605	28.565
167.105	14.473	169.959	20.525	169.572	28.619
167.147	14.527	169.995	20.686	169.358	28.848
167.188	14.575	170.008	20.743	169.295	28.902
167.239	14.631	170.012	20.798	169.212	28.959
167.38	14.798	170.025	21.014	169.11	29.013
167.418	14.845	170.035	21.07	168.42	29.231
167.467	14.901	170.068	21.238	168.116	29.288
165.711	15.119	170.106	21.509	167.737	29.345
167.557	15.173	170.125	21.671	167.33	29.397
167.732	15.228	170.134	21.726	163.718	29.569
167.774	15.285	170.14	21.78	124.324	29.651
167.93	15.5	170.158	21.94	119.63	29.691
167.961	15.557	170.166	21.998	112.115	29.743
168.004	15.616	170.199	22.326	104.996	29.798
168.138	15.829	170.208	22.493	101.853	29.852
168.242	16	170.212	22.549	99.414	29.899
168.324	16.159	170.223	22.604	97.344	29.954
168.364	16.215	170.227	22.765	95.913	30.01
168.397	16.272	170.228	22.821	94.734	30.066
168.427	16.319	170.237	22.879	93.361	30.123
168.548	16.535	170.24	23.038	92.158	30.178
168.611	16.637	170.24	23.101	90.92	30.235
168.607	16.695	170.245	23.815	90.027	30.284
168.637	16.749	170.251	23.982	88.872	30.34
168.671	16.806	170.252	24.031	87.641	30.399
168.811	17.021	170.246	24.087	87.016	30.455
168.841	17.076	170.239	24.519	86.332	30.511

Actuator: 1 Channel:0	Actuator: 1 Channel:1
A1 Load : *Current (kN)*	A1 Stroke : *Current (mm)*
85.15	30.568
83.923	30.626
82.516	30.673
80.745	30.735
78.159	30.794
76.588	30.842
74.962	30.897
73.475	30.954
71.806	31.011
70.325	31.069
69.14	31.119
68.004	31.176
67.044	31.224
65.898	31.279
64.42	31.344
63.306	31.401
62.463	31.447
61.501	31.504
60.375	31.56
59.196	31.617
58.125	31.675
57.049	31.729
56.239	31.781
55.11	31.837
53.976	31.893
53.024	31.951
51.935	32.007
50.854	32.064
49.737	32.121
48.847	32.17
47.845	32.226
46.737	32.279
45.638	32.338
44.645	32.387
43.423	32.444
42.126	32.501
40.816	32.557
39.275	32.616
38.084	32.662
36.826	32.719
35.285	32.776
33.589	32.832
31.597	32.891
29.4	32.948
27.304	32.997
24.514	33.054
20.132	33.113